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3D workflows in orthodontics, maxillofacial surgery and prosthodontics

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Digitally Designed Surgical Guides for Placing Extraoral Implants in the Mastoid Area

This chapter is an edited version of:

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Abstract

Aim: When planning implant therapy, knowledge of the bone volume in the implant area is needed to plan and place implants in the most appropriate locations from the prosthetic and surgical perspectives. Commercial software for digital planning of implants in the craniofacial region is not yet available. This article describes a method that enables digital planning of extraoral implants in the mastoid region utilizing commercially available computer-aided design (CAD) software and rapid-prototyping techniques to manufacture a corresponding surgical guide.

Materials and methods: With the aid of CAD software designed for reverse engineering and three-dimensional animation, digital implant planning based on cone beam computed tomography (CBCT) scanning was performed. On the basis of this planning, surgical guides were digitally designed to facilitate the placement of dental implants in the mastoid area. The guides were fabricated using rapid prototyping. The appropriateness of the digitally designed surgical guides for placing extraoral implants was tested on six human cadaver heads with simulated bilateral ear defects. After implant placement, a second CBCT scan was performed to compare preoperative planning with the actual postoperative implant positions.

Results: Twenty-four implants were placed. The surgical guide helped the surgeon to place the implants at the preoperatively planned positions. Comparison of the CBCT scans revealed that adequate accuracy of implant placement was achieved, both for deviation of the neck (1.56 ± 0.56 mm) and the tip (1.40 ± 0.53 mm) of the implant, and for deviation of the angulation of the implant (0.97 ± 2.33 deg).

Conclusions: The presented method for digitally planning extraoral implants in the mastoid area and designing surgical guides allows for placement of implants in the mastoid area in close proximity to the preoperatively planned implant position. The actual implant positions were satisfactory both surgically and prosthetically.

Introduction

Maxillofacial defects can be caused by genetic disorders, trauma and ablative tumour surgery. Patients with such defects can suffer from aesthetic and psychological problems.¹ To rehabilitate such patients, these defects are usually covered with maxillofacial prostheses made of silicone. In the past, these prostheses were usually attached to the patient's skin with glue.² Nowadays, implants are often used to retain maxillofacial prostheses.^{3,4} Prostheses for the ear, nose, and orbit retained by implants have been shown to be reliable, and from a patient's perspective they are highly appreciated treatment options for the restoration of these defects.⁵⁻⁷

Most often, maxillofacial implants are placed in the upper and lower orbital rim (orbital prostheses), in the mastoid area (ear prostheses), and in the nasal floor (nose prostheses). For the placement of intraoral implants, particularly in compromised areas, special software programs, for example, NobelGuide (Nobel Biocare) and SimPlant (Materialise), are currently available to help the surgeon and the prosthodontist to digitally plan the placement of intraoral implants. With this software, computed tomography (CT) or cone beam CT (CBCT) data are used to plan the implant position via computer, with which a digitally designed surgical guide is fabricated. The surgical guides for implant placement in the mandible or maxilla obtained with this method enable the surgeon to place the implants in the preoperatively planned and prosthodontically preferred positions, thereby ensuring a sufficient volume of bone at the implant sites.

Recent advances in computer technology have allowed maxillofacial prostheses to be designed digitally.^{8,9} Various tools have been developed that can help the surgeon with digital planning of extraoral implants, eg, robot-assisted placement of craniofacial implants, placement of implants with image guidance.^{10,11} The latter technique is based on a calibrated image guidance system and a corresponding stereotactic burr handpiece. The handpiece is used to identify the implant site as its position is projected into the existing CT dataset. The implant site is determined by tattooing the periosteum with a methylene blue dye, applied by a tattoo needle penetrating through the skin, after which the maxillofacial surgeon can place the implants. Although the accuracy of image-guided systems has been claimed to be very high, this technique is dependent on a variety of cumulative and interactive factors involved in data acquisition and surgery. Another example of using digital technology is described by Schlieper et al 2001.¹² In their study patients were scanned with conventionally fabricated templates in situ. The templates incorporated titanium pins in the preferred implant positions. The acquired CT data were used to evaluate the chosen implant positions. Few case reports on the use of digital technology for planning extraoral

implants are available.^{13,14} Furthermore, no commonly available tools have been described that are specifically designed for pre-operative digital planning of extra-oral implants and the corresponding bone-supported surgical guides. This statement is supported by the conclusions of Widmann and Bale¹⁵ in their review of the accuracy of computer-aided implant surgery. In 2006, these authors stated that long-term clinical studies are needed to examine all aspects of treatment success to confirm the value of the strategies and to justify the additional radiation dose, efforts and costs. In other words, a full digital workflow and the exact realization of accurate planning and placing of extra-oral implants is not yet possible with the routine surgical guides, as was already mentioned some years before.^{10,12} As a result, in most cases, planning of extra-oral implants to support maxillofacial prostheses is still performed according to conventional planning with the risk that implants may be placed in areas with insufficient bone volume to guarantee implant stability.^{16,17} As a consequence, the surgeon may be directed during surgery toward a prosthetically less appropriate implant position. Furthermore, conventional methods cannot be used when placing implants during ablative surgery, as ablation is not very precise, while the surgeon must have good insight into the actual bone volume of the planned (and from a prosthetic perspective, still acceptable) implant position, which can be hazardous when implant placement is performed in the mastoid and/or orbital areas. In the mastoid area, for example, the bone contains air compartments, which limit the areas where implants can be placed. With digital planning, CT or CBCT data are used, providing detailed data about the actual bone volume at the most prosthetically preferable spots, whereas with conventional planning it is likely that the implants will not be placed in prosthetically ideal positions because of a lack of knowledge of the bone volume in the designated implant areas.

Another important problem with “conventional” surgical guides is related to placing the surgical guide in the correct position during surgery owing to their inaccurate fit. Placement of a conventional surgical guide can be difficult, as such guides are made on plaster casts. Plaster casts do not mimic the resilience of the soft tissues, although the guide must be applied on soft tissue during implant surgery. Therefore, it would be beneficial if digital planning of extraoral implants could be performed in a similar fashion as dental implants in compromised intraoral conditions. If information about the actual bone volume and soft tissue configuration were available, digital planning and placement of extraoral implants would be more predictable. For example, a surgical guide that is placed directly on the bone and has a stable fit can ensure that the surgeon places the implants in the preoperatively planned positions, thus improving the prosthetic outcome. Because specific planning software for extraoral implants is not yet commercially available, the authors have developed

an alternative method to digitally plan the placement of implants to retain maxillofacial prostheses through the use of commercially available computer-aided design/computer-assisted manufacture (CAD/CAM) software. The present article aims to describe a reliable method that enables digital planning of extraoral implants in the mastoid region utilizing commercially available CAD software and rapid-prototyping techniques to manufacture a corresponding surgical guide.

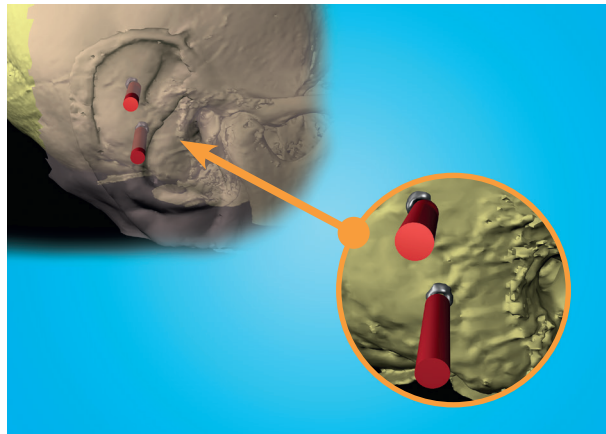
Materials and Methods

CBCT based implant planning and surgical guide design

CBCT data (3D Exam, KAVO) of six edentulous cadaver heads, all with unaffected soft tissues, were converted to surface models with Mimics software (Mimics, Materialise, Leuven, Belgium) using an optimal threshold to depict either the bone or the skin and imported into 3ds Max (Autodesk, San Rafael, California, USA). To mimic the clinical situation, the CBCT machine was set to a voxel size of 0.3 mm which results in a resolution higher than that prescribed for planning implants using Nobelguide (Nobelbioresearch, Gothenburg, Sweden) or SimPlant (Materialise, Leuven Belgium).

In the 3dsMax software, a library with a variety of dental implants was made, with lengths

Figure 1: Preoperative implant planning on one of the human cadaver heads. The planned implants (red cylinders, diameter 4 mm) are centered in the preferred implant positions (blue circles, diameter 7 mm). The actual implants (grey) were placed within this area in the most preferable locations, ie, right underneath the cartilage edge of the external ear.



and diameters corresponding to dental implants that are customarily employed extraorally to retain maxillofacial prostheses. Around the implants, a three-dimensional (3D) cylinder was designed in the software with a diameter of 6 mm (ie, 2 mm larger than the 4-mm diameter of the implants) (**figure 1**). This cylindric zone depicted a safety zone within which the implants could be safely placed from a surgical point of view; this also allowed the prosthodontist to fabricate the planned maxillofacial prosthesis. An experienced maxillofacial surgeon, an experienced maxillofacial prosthodontist, and a specialist proficient with the

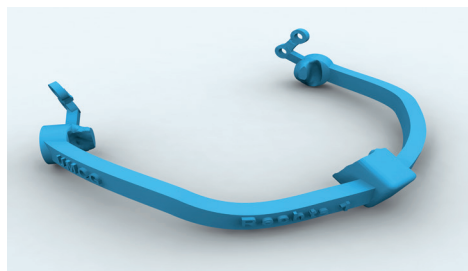


Figure 2a: Digitally designed surgical guide that was fabricated via rapid prototyping to place implants in the mastoid area.

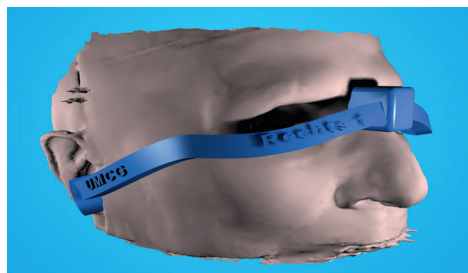


Figure 2b: Three reference points were used when designing the guide: the bridge of the nose (nasion), the tragus, and the external meatus (skin contact point). At the implant locations, the guide makes full bone contact.



Figure 2c: Testing the fit of the surgical guide on the head of the cadaver.

7

forementioned software planned the preferred implant positions, taking into consideration the prosthetic and surgical needs, as well as the implant characteristics and safety zone around the implants. The virtual implants were exported as .stl files. These files could then be imported into the Mimics software to ensure that the planned implant locations coincided with bone. Based on the planning, a surgical guide was digitally designed in the 3ds Max (figure 2). At the implant locations the guide was designed to fit the bone surface, aiming for good fit and stability, whereas the remainder of the guide was designed to fit to three points on the skin surface: the region bordering nasion on the head, the external meatus, and the tragus of the former ear (figure 2). These anatomical points are easy to locate and demonstrate typical characteristics that ensure a good fit and enable reproducible positioning of the guide during surgery in accordance with the digital planning. Because the skin in the implant locations was not firmly attached to the underlying bone, predictable flapless surgery was not possible. It was therefore decided that the bone would be used to stabilize the surgical guide during osteotomy preparation.

At the site of the virtual implants, a 5.1-mm hole was modelled in the surgical guide. A

5.0-mm metal insert could be placed in this 5.1-mm-diameter hole to serve as a guide for the first twist drill. The guide was made to fit to the bone surface by digitally subtracting the bone from the guide design, a so-called Boolean operation. A second Boolean operation was performed by subtracting the soft tissues from the guide design. The resulting guide would therefore fit the bone at the implant site and would fit the soft tissues at the corresponding points.

The digitally designed surgical guides were exported as .stl files and were sent to Tridantica, a company that converts digital 3D models into physical models. At Tridantica, the digital 3D guide was converted into an actual surgical guide using rapid prototyping and infusion technology.

Testing the method

To test the method of planning the extraoral implants and designing the corresponding surgical guide in 3D animation software, the aforementioned six human cadaver heads were used. Preoperatively, all heads were scanned and digital surgical guides for the placement of two mastoid implants on each side of the heads were fabricated, as detailed earlier. After the fabrication of the surgical guides, bilateral removal of the ears was performed by an experienced oral and maxillofacial surgeon. The bone of the mastoid area was uncovered, and the surgical guides were placed. A total of 24 implants (Southern Implants), all 4.0 mm in diameter, were placed in the digitally planned positions with the aid of the surgical guide (figure 3).

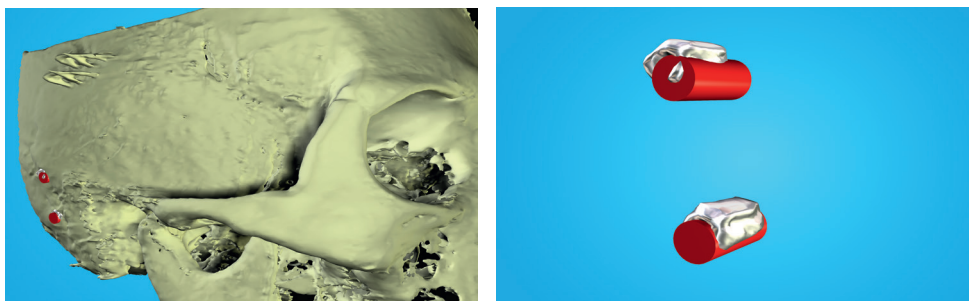


Figure 3: Comparison of planned and actual implant positions. (a) By super-imposing the preoperative and postoperative CBCT data, the pre-operative implant positions (red) can be compared with the actual implant locations. (b) The implants (grey) were placed in close proximity with the preoperatively planned locations (red).

Analyzing the results

Postoperatively, CBCT scans were made of the cadaver heads using the same CBCT machine that had been used for the preoperative scans. These scans were employed to compare the actual implant positions with the preoperatively planned implant positions using the same threshold values used in the preoperative scans (figure 3b). The postoperative data were imported into Geomagic Studio software (Geomagic GmbH) and matched with the preoperative planning data using an iterative closest point registration algorithm. Linear measurements were made between the neck and tip of the planned and actual implant positions. Lines were constructed through the centers of the implants, and the angle between the planned and actual implant positions was measured.

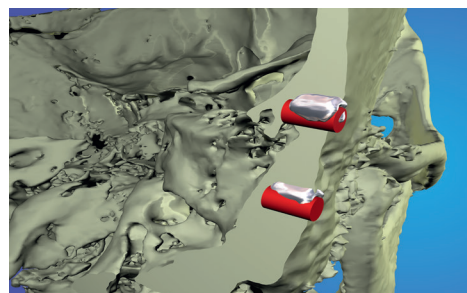


Figure 4: Sectional plane of the mastoid area with the actual implant locations. The implants (grey) are completely surrounded by bone and in close proximity with the pre-operatively planned locations (red).

Results

In all, 24 implants were placed. The surgical guides, which were easy to position and had good fit and stability, enabled the surgeon to place the implants at the preoperatively planned positions (figure 4). Analysis of the differences between the actual and planned position of each implant revealed a mean deviation at the neck of the implant of 1.56 ± 0.56 mm (range, 0.66 to 2.76 mm), a mean deviation at the tip of the implant of 1.4 ± 0.53 mm (range, 0.64 to 2.81 mm), and a mean angular deviation of 0.97 ± 2.33 degrees (range, 0.51 to 3.69 deg). From a prosthetic point of view, the implants were in very good positions, and the ear prostheses were fabricated as planned (figure 1).

Discussion

The digitally designed surgical guides facilitated placement of extraoral implants in preferable positions. The fit of the surgical guides was appropriate, and the guides were held in place manually with ease. Because commercial software specifically for digital planning of extraoral implants is not yet available, two commercial software programs were combined to plan the implant locations and design the guides: Mimics to convert the CBCT data to a surface model, and 3ds Max to plan the implant positions and model the corresponding surgical guide.

The advantage of digital planning is that one can visualize the implant locations and plan the implants in the most preferable positions (eg, avoiding air chambers in the bone) from a prosthetic point of view. There are two major advantages of using the described method versus other methods described in the literature. First, this method is relatively inexpensive (sophisticated technology is not needed). Second, it is a simple technique that requires little training. Clinicians without a CBCT scanner can obtain a CT scan in a nearby hospital. Rapid-prototyping services are provided over the Internet by many companies worldwide. The actual placed implants were between 0.66 and 2.81 mm from their planned positions. Van Assche et al¹⁸ reported deviations of 0.7 to 2.4 mm for intraoral implants, and the meta-regression analyses of Schneider et al¹⁹ revealed mean deviations of the implants of 1.07 mm at the entry point and 1.63 mm at the apex; the results obtained from the present study are comparable.

However, most of the studies included in the meta-analysis of Schneider et al involved fully dentate or partially edentulous subjects, which enhances the stability of the surgical guide. Thus, taking into account that a slight deviation of the actual implants compared to the planned implants in the mastoid region was not accompanied by problems in the fabrication of an optimal implant-retained auricular prosthesis, the observed mismatch between the planned and actual implant positions of the present method is highly acceptable from a prosthetic point of view. It may even call into question whether a comparably accurate result can be achieved with conventional planning.

Conclusions

With the described method, it is possible to digitally plan extraoral implants in the mastoid area. With the aid of a digitally designed surgical guide, the planned implants were placed in close proximity to the preoperatively planned implant positions. These positions were more than satisfactory from the surgical and prosthetic points of view to allow for optimal implant-retained prostheses.

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